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Differential Hydrological Properties of Forest Litter Layers in Artificial Afforestation of Eroded Areas of Latosol in China

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Abstract: Litter is one of the key components of the forest ecosystem and plays a role as the second active layer influencing hydrological processes, which has affected the global water cycle. Soil- and water-conservation forests were constructed by artificial afforestation as a part of vegetation restoration in the eroded area of Latosol, and little is known about the differences in the hydrological properties of vegetation restoration in the eroded area of Latosol in the tropical region. We investigated the litter thickness, mass, and hydrological properties in three soil- and water-conservation forests (*Eucalyptus robusta*, *Hevea brasiliensis*, and *Acacia mangium*) through in situ surveys and laboratory experiments. The results showed that (1) the total litter thickness varied from 2.16 to 5.53 cm and was highest in the *A. mangium* forest. The total litter mass for *A. mangium*, 14.66 ± 1.09 t·ha^{-1}, was significantly higher than that for *E. robusta* (5.45 ± 0.59 t·ha^{-1}) and *H. brasiliensis* (3.01 ± 0.14 t·ha^{-1}). The mass of the semi-decomposed litter (SDL) layer was markedly higher than that of the un-decomposed litter (UDL) layer. (2) The maximum water-retention capacity (W_{max}) and effective water-retention capacity (W_{eff}) of the SDL layer were larger than the UDL layer for three forest plantations. The W_{max} and W_{eff} for the *A. mangium* stand were significantly higher than those for the *E. robusta* and *H. brasiliensis* stand. (3) The water-absorption rate of the SDL and UDL layer were highest at the onset of the immersion experiment, declined exponentially with time, and especially declined rapidly in the first 2 h. A higher water-holding capacity of *A. mangium* may be more effective in enhancing rainfall interception, minimizing splash erosion, and decreasing surface runoff. These results indicate that planting *A. mangium* in *E. robusta* and *H. brasiliensis* forests and then turning them into mixed forests should improve soil and water conservation and maximize their ecological benefits.

Keywords: soil- and water-conservation forest; Mahuangling Watershed; hydrological properties; litter layer

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1. Introduction

The forest is an important component of the terrestrial ecosystem and plays a key role in the global water cycle, which has been affected by forests' influence on hydrologic processes [1–4]. The forest litter is the second active layer influencing the hydrological behavior of the forest ecosystem [5–7], which is often used to scientifically evaluate the function of water conservation [8,9]. More and more studies have added evidence of a substantial impact of litter on water conservation with a substantial litter layer in forest ecosystems [6,10–13]. However, the litter layer structure, litter coverage, litter mass, and hydrological properties of plantation forests in the eroded area of Latosol in tropical zones, as well as their water-conservation function, have not been widely studied. With optimization of the stand structure of vegetation restoration for ecological engineering construction in this study area, the quantity and quality of ecosystem services, such as water conservation provided by those forest stands, should be further studied.

Forest litter, a sponge layer between the atmosphere and the soil, plays a key role in hydrological processes [7,14–16], which by intercepting rainfall, relieving rainfall splash, and delaying or reducing surface runoff, infiltrates into the soil to participate in the water cycle [11,17,18]. This process largely affects a forest ecosystem's water budget [16,19,20]. As a result, the thickness and mass of the litter and its water-holding capacity depend on forest vegetation [3,13,14]. Compared to coniferous forests, the broad-leaved forest forms a broad, dense canopy and increases the interception capacity of rainfall [3,7,21,22]. The properties of the broad-leaved forest ecosystem highly favor water conservation of the catchment [6,17,23]. However, we know little about the differences in hydrological properties of broad-leaved forests in eroded areas of Latosol's tropical zones.

Soil and water loss have occurred in the red soil region of Southern China since the 1950s [24], which is the region with the second greatest severity of soil erosion after the Loess Plateau [25,26]. The implementation of the State Key Forestry Ecological Projects in vulnerable ecological regions recognized the main measures to prevent soil and water loss and to greatly improve the ecological environment [27–30]. Vegetation restoration is an important part of Forestry Ecological Projects, which plays a key role in water and soil conservation [13,31–34]. The eroded area of Latosol in Danzhou County, Hainan Province, features serious soil erosion due to extensive deforestation in the 1960s to 1980s; vegetation is scarce, and thus, the soil is loose and erosion gullies are densely distributed in this region during the rainy season [35]. Starting in 2000, vegetation restoration has been conducted by planting soil- and water-conservation tree species such as *Eucalyptus robusta*, *Hevea brasiliensis,* and *Acacia mangium*, and water and soil loss have been effectively controlled, but little is known about the hydrological properties of these forests.

In this study, three typical forest plantations in an eroded area of Latosol in Mahuangling Watershed were selected, *Eucalyptus robusta*, *Hevea brasiliensis*, and *Acacia mangium* forests, and we quantified the litter thickness, mass, and hydrological properties to guide ecological engineering construction in the eroded area of Latosol.

2. Materials and Methods

2.1. Study Sites

This study was conducted in Mahuangling Watershed at the Mahuangling Soil and Water Conservation Monitoring Station at Danzhou City, Hainan Province, China (19°41′~19°47′ N, 109°24′~109°30′ E) (Figure 1). The region has a tropical monsoon climate. The annual temperature is 23.5 °C. The highest temperature recorded in this region was 41.1 °C, and the lowest was 2.9 °C. The mean annual precipitation is 1815 mm, with a distinct wet (May to October) and dry season (November to April). The wet season receives about 80~85% of the annual rainfall. The highest elevation is 161.6 m a.s.l., and the topography consists of gentle sloping hills. The bedrock mainly consists of granite, and the soil at this site is Latosol soil. Because of over-harvesting and deforestation between the 1960s and 1980s, soil and water loss were serious, and vegetation was scarce in this area, which caused serious soil erosion in the already eroded area of Latosol. After vegetation restoration, as a part of the State Key Forestry Ecological Projects conducted in the 2000s in this area, soil- and water-conservation forests were constructed by artificial afforestation, and soil erosion was controlled effectively. Additionally, this study site is now primarily covered by plantation forests, which are dominated by soil- and water-conservation tree species such as *Eucalyptus robusta*, *Hevea brasiliensis,* and *Acacia mangium*. The understory consists of such species as *Melastoma malabathricum*, *Urena lobata*, *Lantana camara*, *Chromolaena odorata*, and *Digitaria sanguinalis,* and the forest coverage rate is more than 75%.

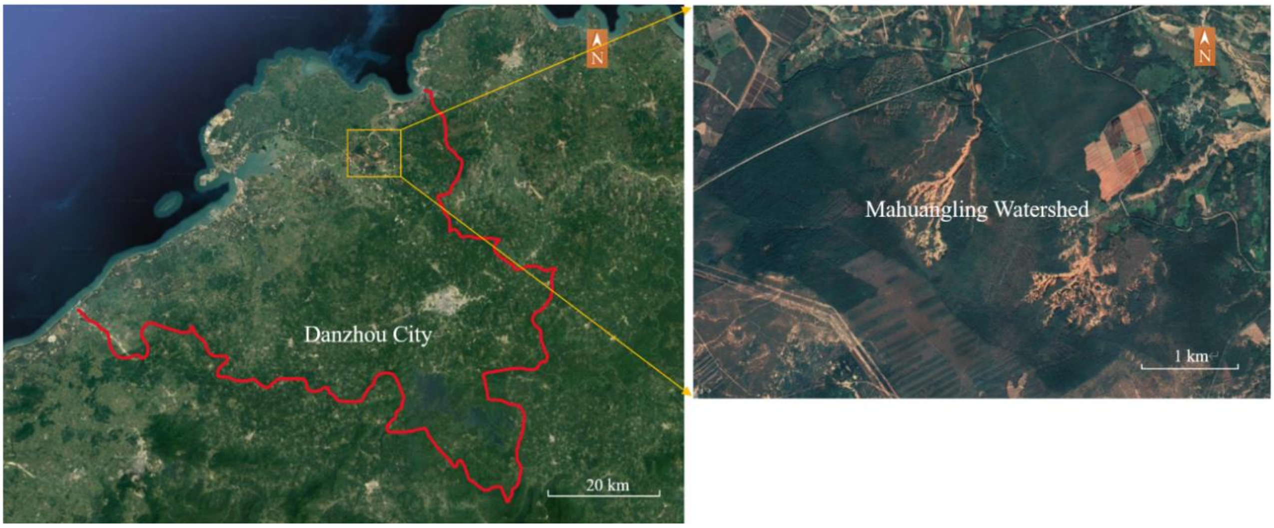

Figure 1. Map of the study and the field area. Mahuangling Soil and Water Conservation Monitoring Station at Danzhou City, Hainan Province.

2.2. Litter Collection

The sites were artificial pure forests of *E. robusta*, *H. brasiliensis,* and *A. mangium*. In mid-January 2021, field sampling from three forest ecosystems (*E. robusta*, *H. brasiliensis,* and *A. mangium*) was conducted at the study site. Three 20 × 20 m plots, standard sample sites, were set up in each forest ecosystem, located in areas away from the road and relatively free of human disturbance. Each site was selected following the protocol of "Observation Methodology for Long-term Forest Ecosystem Research" of the National Standards of the People's Republic of China (GB/T 33027-2016). Within the sites, trunk diameter at breast height (1.3 m), tree height, and canopy density were measured. The basic site and stand information are presented in Table 1.

Table 1. Characteristics of the sampling sites.

Vegetation Type	Stand Age (a)	Average Tree Height (m)	Average Breast Diameter (cm)	Canopy Coverage	Slope (○)
E. robusta	22	16.90 ± 2.10	20.10 ± 5.30	0.75	2~5
H. brasiliensis	23	15.50 ± 1.70	13.90 ± 2.70	0.82	2~5
A. mangium	22	15.00 ± 1.20	16.70 ± 3.50	0.85	2~5

Note: data are presented as mean ± S.D.

Five 0.5 × 0.5 m quadrats were randomly selected for each standard sample site of the forest ecosystem for litter sampling. Intact litter layers were collected, and the semi-decomposed litter (SDL layer) and un-decomposed litter (UDL layer) were graded and bagged separately following the method described in the aforementioned protocol. A total of 90 litter bags (3 species × 3 sites × 5 random quadrats × 2 litter layers) were collected. Four points around each quadrat were randomly selected to measure the average thickness of both the SDL and UDL layers representing that quadrat. The thickness of the total litter layer, as well as its SDL and UDL layer components, was recorded.

2.3. Laboratory Analyses

Litter samples were brought back to the laboratory to determine the fresh mass (m_f). After fresh mass determination, the litter was left to air-dry in the lab and then placed in an oven to dry at 75 °C and weighed to determine the amount of litter mass (m_0) [36]. The litter's water-holding capacity was determined by the indoor water soaking method [3,7]. A 20 g sample of dried litter was placed in a weighted porous nylon bag, which was immersed in a plastic basin filled with clean water and soaked for a predetermined time (0.25, 0.5, 1, 2, 4, 6, 8, 12, or 24 h), and then taken out at the set time and re-weighed to determine the gross wet mass of litter (m_i) after full drainage. The percentage of water held in litter samples after soaking was used as the water absorption rate. The litter water-holding capacity was calculated as follows [3,7,22]:

$$R_i = (m_i - m_0)/m_0 \times 100 \quad (1)$$

where R_i is the water-holding capacity of litter at the immersion time i (i = 0.25, 0.5, 1, 2, 4, 6, 8, 12, or 24 h), m_0 is the dry litter mass, and m_i is the litter mass at the immersion time i after free drainage.

$$R_0 = (m_f - m_0)/m_0 \times 100 \quad (2)$$

Here, R_0 is the water-holding capacity of litter under ambient conditions, m_0 is the dry litter mass, and m_f is the fresh litter mass.

$$R_m = (m_{24} - m_0)/m_0 \times 100 \quad (3)$$

Here, R_m is the maximum water-holding capacity of litter, m_0 is the dry litter mass, and m_{24} is the litter mass soaked for 24 h after free drainage. The R_m was defined as the maximum levels of the respective parameters relative to the amount and the percentage of water-holding during a 24 h soaking period [3,7]. In this study, the water-holding ratio rarely increased after the litter was immersed in water for 24 h; thus, R_m was numerically equivalent to R_{24}.

$$W_{eff} = (0.85R_m - R_0)M \quad (4)$$

$$W_{max} = (R_m - R_0)M \quad (5)$$

Here, W_{eff} and W_{max} are the effective water-retention capacity (t·ha^{-1}) and maximum water-retention capacity (t·ha^{-1}), respectively; M is the unit litter mass (t·ha^{-1}).

2.4. Statistical Analysis

All statistical analyses were performed using SPSS v. 18.0 (SPSS Inc., Chicago, IL, USA). Tests for significant differences in hydrological properties were evaluated by one-way analyses of variance (ANOVA), and the least significant differences (LSD) were determined for multiple comparisons. The significance level was set at $p < 0.05$. The figures were plotted with Origin 2021 software (Origin, Origin Lab, Farmington, ME, USA).

3. Results

3.1. Variations in Litter Thickness and Mass

There was a significant difference in total litter thickness between tree species ($p < 0.001$) (Table 2). Additionally, the UDL layer and the SDL layer litter thickness differed significantly in all stands ($p < 0.05$), and this difference depended on the tree species ($p < 0.001$). The *A. mangium* forest had the highest total litter thickness (5.53 ± 0.32 cm), followed by the *E. robusta* forest (4.73 ± 0.29 cm), and the *H. brasiliensis* forest had the lowest total litter thickness (2.16 ± 0.05 cm). The same pattern was observed in the UDL layer and the SDL layer litter thickness in three tree species (Figure 2a). The litter thickness of the SDL layer of *A. mangium* and *E. robusta* forest was slightly larger than the thickness of its UDL, but the SDL layer of *H. brasiliensis* was lower than the thickness of its UDL ($p < 0.05$).

Table 2. F-statistics from factorial ANOVA to assess tree species and litter layer (SDL and UDL) effects on the litter thickness, mass, total litter thickness, and total litter mass. df: degrees of freedom; SS: sum of squares; MS: mean square; ***: $p < 0.001$.

Variable	Factor	df	SS	MS	F	*p*
Litter thickness	tree	2.84	46.41	23.20	196.35	<0.001 ***
	layer	1.84	3.521	3.52	29.79	<0.001 ***
	tree × layer	2.84	3.84	1.92	16.24	<0.001 ***
Litter mass	tree	2.84	566.67	283.34	590.01	<0.001 ***
	layer	1.84	479.92	479.92	999.36	<0.001 ***
	tree × layer	2.84	254.33	127.16	264.80	<0.001 ***
Total thickness	tree	2.42	92.81	46.41	734.19	<0.001 ***
Total mass	tree	2.42	1132.99	566.49	1087.02	<0.001 ***

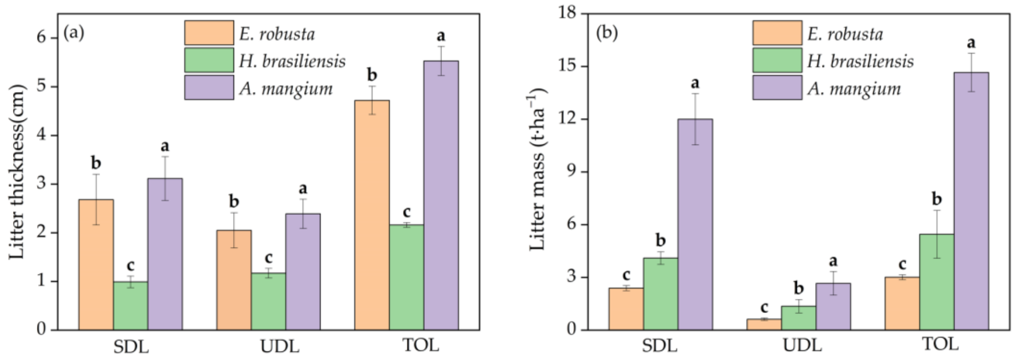

Figure 2. Variations in litter thickness and mass in semi-decomposed litter (SDL) layer and undecomposed litter (UDL) layer of *E. robusta*, *H. brasiliensis*, and *A. mangium*. (**a**) Litter thickness; (**b**) litter mass. For each category, different lowercase letters indicate a significant difference in the mean value among three forest plantations.

There was also a significant difference in litter mass between tree species and litter layers ($p < 0.001$) (Table 2). The total litter mass in *A. mangium* (14.66 ± 1.09 t·ha^{-1}) stand was significantly higher than that in the *E. robusta* (5.45 ± 0.59 t·ha^{-1}) and *H. brasiliensis* (3.01 ± 0.14 t·ha^{-1}) litter layer ($p < 0.001$) (Figure 2b). The mass of the SDL layer was higher than the mass of the UDL layer in all stand types ($p < 0.05$) (Figure 2b). The mass of the SDL layer was 12.00 ± 1.46 t·ha^{-1} for *A. mangium*, larger than the 4.10 ± 0.36 t·ha^{-1} mass of the *H. brasiliensis* and the 2.39 ± 0.15 t·ha^{-1} mass of the *E. robusta* litter layer ($p < 0.001$). The mass of the UDL layer was significantly different and decreased in the order *of A. mangium* > *H. brasiliensis* > *E. robusta* ($p < 0.001$). The SDL litter mass accounted for $75.39 \pm 4.95\%$ of the total litter mass in the *E. robusta* plantation forest, $79.48 \pm 2.47\%$ in the *H. brasiliensis* plantation forest, and $81.65 \pm 5.40\%$ in the *A. mangium* plantation forest.

3.2. Variations in R_m, W_{eff}, and W_{max}

The litter's maximum water-holding capacity (R_m) in the SDL layer was $294.04 \pm 33.19\%$ for *E. robusta*, not significantly different from the value observed for *H. brasiliensis* ($298.03 \pm 30.06\%$), which was higher than $228.97 \pm 38.02\%$ for *A. mangium* ($p < 0.05$) (Figure 3a). The R_m of the UDL layer ranged from $237.91 \pm 22.56\%$ to $247.00 \pm 20.14\%$, which did not differ significantly among *E. robusta*, *H. brasiliensis*, and *A. mangium* ($p > 0.05$). The R_m of *E. robusta* was $266.47 \pm 23.16\%$, which is roughly equal to *H. brasiliensis* ($267.97 \pm 21.37\%$); both stands were higher than $237.99 \pm 22.83\%$ for *A. mangium* ($p < 0.05$). The R_m of the SDL layer was higher than the UDL layer in *E. robusta* and *H. brasiliensis*, but this was not observed in *A. mangium* ($p > 0.05$).

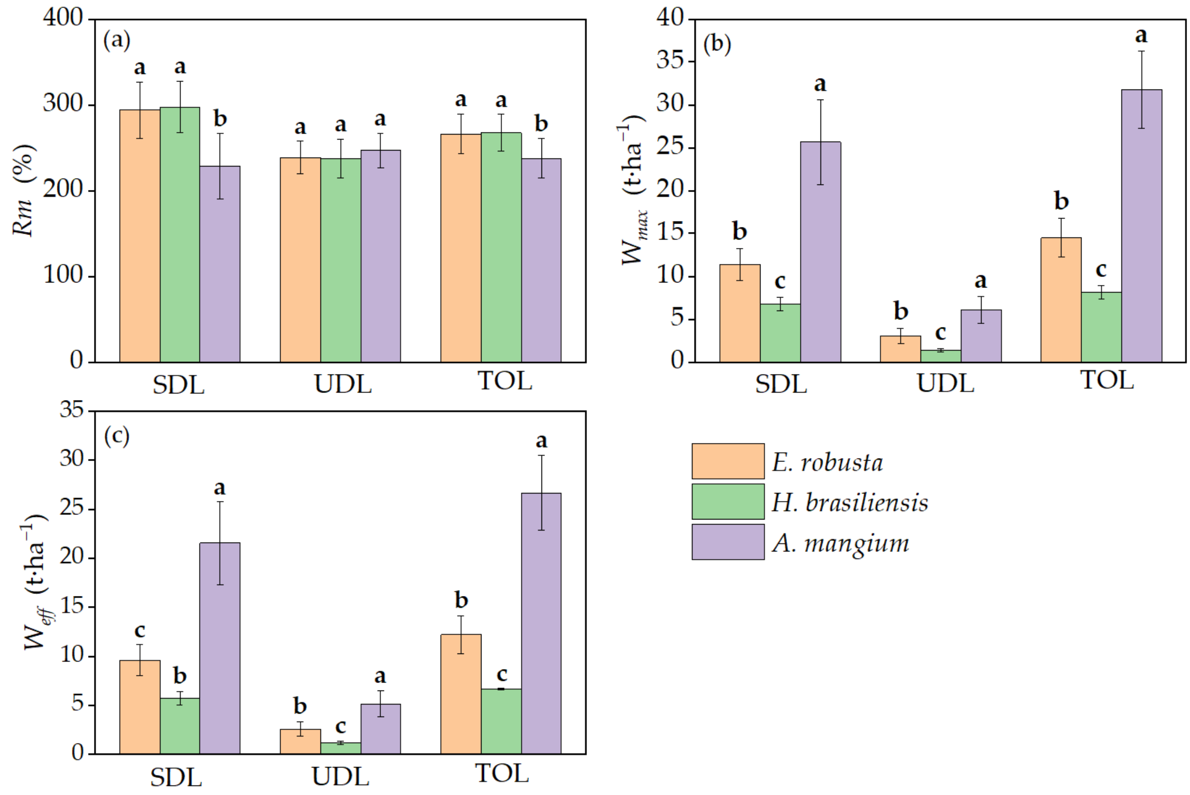

Figure 3. Variations in R_m, W_{eff}, and W_{max} in semi-decomposed litter (SDL) layer and un-decomposed litter (UDL) layer of *E. robusta*, *H. brasiliensis*, and *A. mangium*. (**a**) The litter maximum water-holding capacity (R_m); (**b**) the maximum water-retention capacity (W_{max}); (**c**) the effective water-retention capacity (W_{eff}). For each category, different lowercase letters indicate a significant difference in the mean value among three forest plantations.

The maximum water-retention capacity (W_{max}) significantly varied among the three plantation forests ($p < 0.05$). The W_{max} of *A. mangium* was 31.82 ± 4.48 t·ha^{-1}, significantly higher than 14.53 ± 2.27 t·ha^{-1} for *E. robusta* and 18.21 ± 0.78 t·ha^{-1} for *H. brasiliensis* ($p < 0.05$) (Figure 3b). The W_{max} of the SDL layer was 25.68 ± 4.97 t·ha^{-1} for *A. mangium*, larger than the 11.43 ± 1.86 t·ha^{-1} of *E. robusta* and the 6.80 ± 0.79 t·ha^{-1} of *H. brasiliensis* ($p < 0.05$). Additionally, the W_{max} of the UDL layer was also significantly decreased in the order *A. mangium* > *E. robusta* > *H. brasiliensis* ($p < 0.05$). The W_{max} of the SDL layer was higher than the W_{max} of the UDL layer in all stands ($p < 0.05$).

The effective water-retention capacity (W_{eff}) trends were similar to those observed for W_{max}. The W_{eff} significantly differed in the three plantation forests ($p < 0.05$). The W_{eff} of *A. mangium* was 26.73 ± 3.80 t·ha^{-1}, which was nearly two times the value of 12.24 ± 1.93 t·ha^{-1} W_{eff} for *E. robusta* and nearly four times the value of 6.92 ± 0.66 t·ha^{-1} W_{eff} for *H. brasiliensis* ($p < 0.05$) (Figure 3c). The *A. mangium* forest had the largest interception capacity (note that 1 mm of precipitation is equivalent to 1 t·ha^{-1}), equal to a 26.73 mm depth equivalent of rainfall, and 12.24 mm in *E. robusta* and 6.92 mm in *H. brasiliensis*. The W_{eff} of the SDL layer was 21.57 ± 4.21 t·ha^{-1} for *A. mangium*, significantly higher than the 9.62 ± 1.58 t·ha^{-1} observed for *E. robusta* and the 5.73 ± 0.68 t·ha^{-1} observed for *H. brasiliensis* ($p < 0.05$). Additionally, the W_{eff} of the UDL layer was also significantly decreased in the order *A. mangium* > *E. robusta* > *H. brasiliensis* ($p < 0.05$). The W_{eff} of the SDL layer was higher than the W_{max} of the UDL layer among the three plantation forests ($p < 0.05$).

3.3. Variations in Water-Holding Capacity of Litter

The water-holding capacity varied among the three plantation forests. The water-holding ratio increased with the time of immersion in the water. The water-holding ratio of the SDL layer litter was relatively higher compared to the UDL layer at the same immersion time. After 15 min of water immersion, the water-holding ratio of the SDL layer and UDL layer reached 160.69 ± 23.99% and 107.83 ± 10.56% of their holding capacity in *E. robusta*, respectively, while it was 175.31 ± 26.67% and 155.16 ± 20.20% in *H. brasiliensis*, respectively, and 125.23 ± 28.38% and 108.53 ± 6.39% in *A. mangium*, respectively (Figure 4). After two hours of water immersion, the trend of the increasing water-holding ratio was gentle. The relationship between the water-holding ratio and the immersion time was fitted to a logarithm model observed in both types of litter in the three plantation forests.

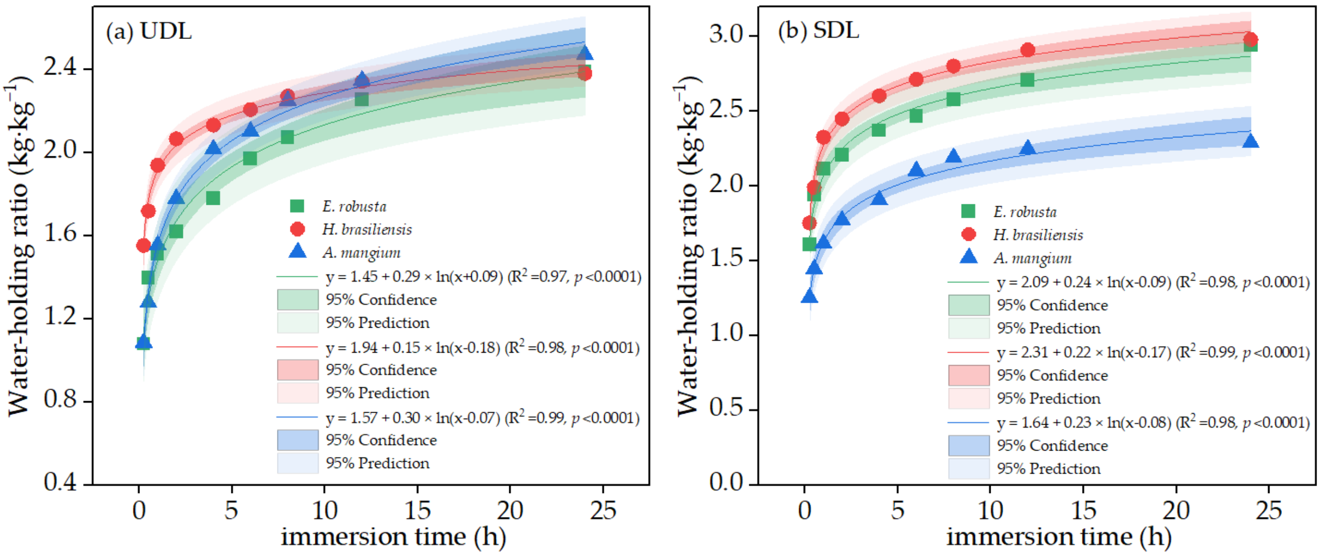

Figure 4. Relationships between the water-holding ratio and the immersion time of (**a**) undecomposed litter (UDL) layer and (**b**) semi-decomposed litter (SDL) layer of *E. robusta*, *H. brasiliensis*, and *A. mangium*.

3.4. Variations in Litter Water-Absorption Rate

The water-absorption rate of the SDL layer and UDL layer were highest at the beginning of the experiment and declined rapidly in the first 2 h. Additionally, the rate slowed down between 2 and 12 h and was nearly unchanged after 12 h (Figure 5). In the first 2 h, the water-absorption rate of the SDL layer was relatively higher than the UDL layer at the same immersion time. At the same time, there were no observable differences in water-absorption rates in *E. robusta*, *H. brasiliensis,* and *A. mangium* plantation forests at the same immersion time. The water-absorption rates of the SDL layer were 2.12 ± 0.19 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$, 2.32 ± 0.27 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$, and 1.61 ± 0.21 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$ for *E. robusta*, *H. brasiliensis*, and *A. mangium*, respectively (Figure 5d–f), after the first hour. Additionally, the water-absorption rates of the UDL layer were 1.51 ± 0.04 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$, 1.93 ± 0.20 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$, and 1.55 ± 0.17 $kg{\cdot}kg^{-1}{\cdot}h^{-1}$ for *E. robusta*, *H. brasiliensis*, and *A. mangium*, respectively (Figure 5a–c). The relationship between the water-absorption rate and the immersion time was fitted to an exponential model observed in both types of litter in *E. robusta*, *H. brasiliensis*, and *A. mangium* plantation forests.

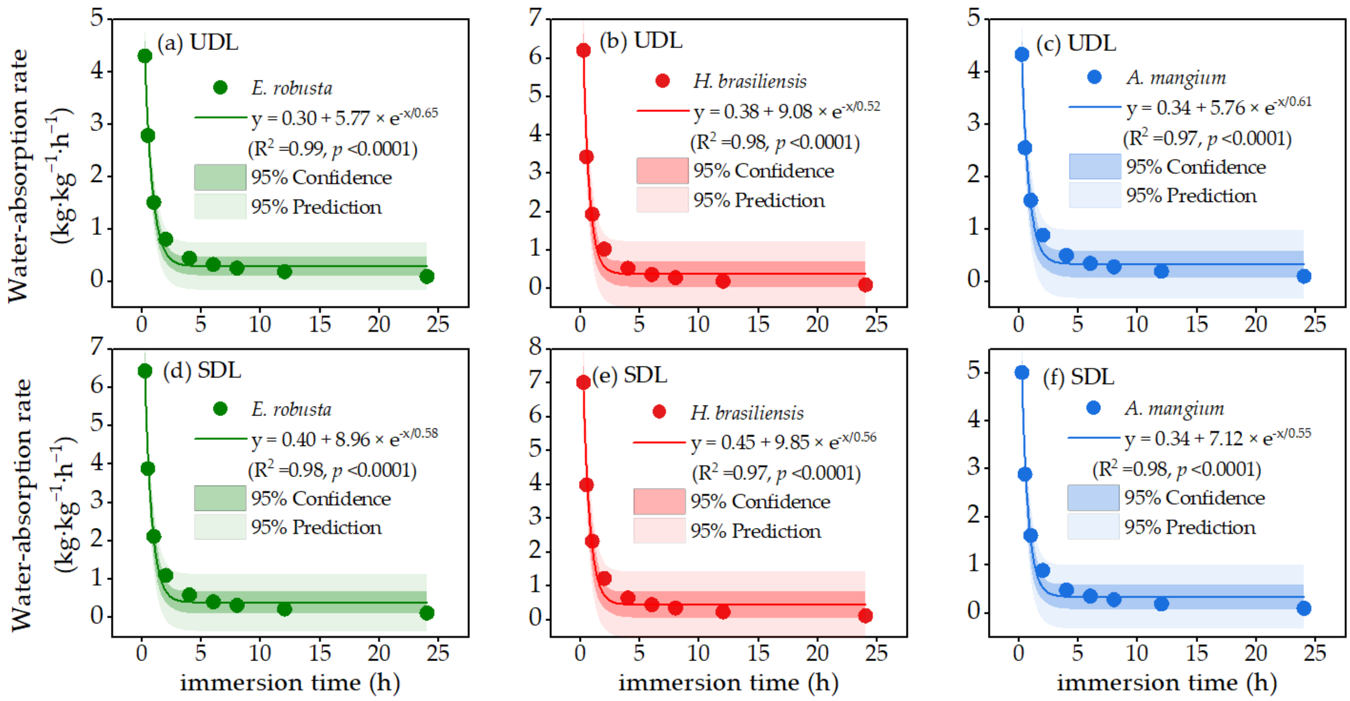

Figure 5. Relationships between the water-absorption rate and the immersion time of un-decomposed litter (UDL) layer for (**a**) *E. robusta*, (**b**) *H. brasiliensis*, and (**c**) *A. mangium* and of semi-decomposed litter (SDL) layer for (**d**) *E. robusta*, (**e**) *H. brasiliensis*, and (**f**) *A. mangium*.

4. Discussion

Forest litter is the second active layer influencing the hydrological behavior of the forest ecosystem and thus affects the global water cycle [3,8,9]. The litter layer is reported to substantially reduce evaporation from surface soil [5,6]. Therefore, a thick litter layer or the conservation of the litter layer may favor moisture retention in shallow soil [7,10,13]. In this study, the total litter thickness varied from 2.16 to 5.53 cm and was highest in the *A. mangium* forest, which means that the *A. mangium* forest greatly reduces evaporation compared to *E. robusta* and *H. brasiliensis* forests. The litter thickness of the SDL layer of *A. mangium* and *E. robusta* forests was slightly larger than the thickness of its UDL, but *H. brasiliensis* showed the opposite tendency. This may be explained by the fact that the litter of *H. brasiliensis* decomposes more easily than that of *A. mangium* and *E. robusta*. Zhou et al. [22] also found that the thickness of semi-decomposed litter was significantly higher than that of un-decomposed litter in coniferous forests. However, a smaller thickness of semi-decomposed litter compared to un-decomposed litter in broad-leaved forests was also reported by Li et al. [3]. Moreover, we also found a significant difference in the litter mass between tree species and the litter layer, it is especially higher in the *A. mangium* forest, which suggests that the *A. mangium* forest could favor rainfall interception. SDL litter mass accounted for 75.39%~81.65% of the total litter mass, which was higher than the UDL layer; they also found that the mass of the SDL layer was higher than the UDL layer, which is consistent with previous reports [3,7,22]. However, on the other hand, more rainfall that is intercepted by litter will evaporate back into the atmosphere [4,16,17]. The net effect of litter on the forest's surface water flux deserves further study.

The maximum water-holding capacity of litter (R_m) defines the effectiveness of unit mass litter in retaining water [7,9,22]; because of the variation in canopy density and litter coverage in different forest ecosystems, they differed in terms of their water-holding capacity [4,12,13,37]. In this study, the *A. mangium* stands showed a lower R_m than did the *E. robusta* and *H. brasiliensis* stands. This difference in hydrological properties of three evergreen broad-leaved forests could be attributed to the difference in the physical and chemical properties of the litter composition of the leaves, dead branches, and seeds.

Additionally, this difference could be attributed to the litter defoliation period since the litter components of *A. mangium* have thicker cuticles than *E. robusta* and *H. brasiliensis*. Additionally, we found that the R_m of the SDL layer in *E. robusta* and *H. brasiliensis* was higher than that of the UDL layer, but this was not observed in *A. mangium*. Our results showed that *E. robusta* and *H. brasiliensis* have a higher degree of fragmentation, a larger surface area per mass unit, and fewer dead branches in general [6,22]. These results are consistent with studies by Li et al. [3] and Chen et al. [7]. Further studies are needed on the biological and hydrological mechanisms underlying the above evidence—especially focusing on the litter decomposition rates and processes, such as the litter decomposition half-life—to better understand such differences among evergreen broad-leaved forests.

The maximum water-retention capacity (W_{max}) depends on the litter mass, litter water content under ambient conditions, and the nature of precipitation [17,23,38]. Our study showed that the W_{max} of *A. mangium* was 2.14 and 1.74 times that of *E. robusta* and *H. brasiliensis*, respectively. Dong et al. [39] reported that the maximum water-retention capacity of *A. mangium* was higher than *E. robusta*. These results could be attributed to *A. mangium* having a greater litter mass and being more effective, which is consistent with previous reports that showed that the maximum water-retention capacity of the litter layer depends on the litter coverage and storage [7,10,12]. Moreover, we found that the W_{max} of the SDL layer was higher than that of the UDL due to greater mass and a more effective SDL layer. Chen et al. [7] reported a higher water-retention capacity of the semi-decomposed OF layer compared to the non-decomposed OL layer in two forests ecosystems; Zhou et al. [22] also found that the maximum water-retention capacity of semi-decomposed litter was significantly higher than that of un-decomposed litter. However, Li et al. [3] reported that the maximum water-retention capacity of the semi-decomposed OF layer was smaller than that of the non-decomposed OL layer in a broad-leaved forest, while the maximum water-retention capacity of the OF layer was higher than OL layer in a coniferous forest. Additionally, Bai et al. [38] showed a higher water-retention capacity in broad-leaved forest litter compared to coniferous forest litter. A comprehensive study is needed to systematically investigate litter characteristics and their hydrological properties across different forest ecosystems in different climate regimes.

The effective water-retention capacity (W_{eff}) defines the effective interception of precipitation by litter, which is a hydrological property that could be used to determine the potential to absorb rainwater in a forest ecosystem and to control surface runoff [3,4,9]. This value varies depending on the litter storage, the water content of these materials, and the nature of precipitation [6,16]. In this study, the results suggest that the litter layer can theoretically intercept up to 26.73 mm of rainfall in *A. mangium*, 12.24 mm in *E. robusta,* and 6.92 mm in *H. brasiliensis*. This is a substantial capacity to minimize the splash erosion from heavy rainfall. The results indicated that *A. mangium* had the greatest water-retention capacity and decreased runoff, which made the best of the effective interception of rainfall [5,7,40]. This may be overestimated due to the "umbrella effect" of large intact leaves on the surface of the litter layer [3]. However, it is also largely unknown whether W_{eff} could be reached in situ for a given rainfall [7]. Moreover, Acharya et al. [4] measured litter water content in situ, which may provide more realistic estimates of rainfall interception by litter. Systematic measurement in situ needs to be conducted in further studies to improve the water flux estimation of forest grounds.

In this study, our results showed a rapid rise in the litter water-holding ratio in three plantation forests and at the first two-hour onset of the water-immersion experiment in the laboratory, which is consistent with studies by Li et al. [3] and Chen et al. [7], and likely attributed to drier litter having a lower matrix water potential. Additionally, the litter water-absorption rate decreased exponentially due to the litter becoming moist and nearly unchanged after 12 h. Moreover, the water-holding ratio of the SDL layer was relatively higher compared to the UDL layer. This may be explained by the fact that the SDL layer has a higher degree of fragmentation and a larger surface area per mass unit [3,4,13,20].

Among the *A. mangium*, *E. robusta,* and *H. brasiliensis* forest plantations in our study, the *A. mangium* forest had the greatest litter storage and water-retention capacity. From the perspective of the water conservation function after vegetation restoration, our results suggest that *A. mangium* of vegetation-restoration-type stands have a dense litter layer suitable for intercepting rainfall, reducing runoff, and buffering the impact of heavy rainfall. Additionally, from a management perspective, a thick and dense litter layer may favor a delay and decrease in the formation of surface runoff, may minimize splash erosion, and may be considered favorable to rainfall infiltration and potential streamflow enhancement. Strategic removal of some unhealthy *E. robusta* and *H. brasiliensis* trees and the planting of *A. mangium* can transform artificial pure forests into mixed forests and will likely improve the hydrological effects in mixed forests. The impact of the transformation of artificial pure forests into mixed forests on the hydrologic budget requires further in situ studies to determine the multiple ecosystem services provided by forests [31,33,41].

5. Conclusions

The plantation of *A. mangium*, *E. robusta,* and *H. brasiliensis* forests in the eroded area of Latosol in the Mahuangling Watershed causes uncertainty regarding their current water-conservation function. We studied the hydrologic properties of the litter layer in three forest ecosystems, finding a much greater litter thickness and higher litter mass in *A. mangium* than in *E. robusta* and *H. brasiliensis* forests. The effective water-retention capacity of the undecomposed layer was relatively higher than the semi-decomposed layer, especially in *A. mangium* forests, and is likely more effective in intercepting rainfall and decreasing surface runoff. There were clear differences in the hydrological effect of the different forest types in this eroded area of the Latosol region, with the *A. mangium* forest generally favoring hydrological properties. Therefore, in forest restoration in the eroded areas of Latosol, the preservation and restoration of mixed forests by removing some unhealthy *E. robusta* and *H. brasiliensis* trees and planting *A. mangium* should be strengthened to improve the water-conservation capacity and to maximize its ecological benefits. Further studies should aim at conducting comprehensive evaluations of the soil- and water-conservation capacity when transforming artificial pure forests into mixed forests using in situ measurement in the watershed.

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